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Published in:
Energy and sustainable growth: is sustainable growth possible. Vol. 1

Publication date:
1997

Linking macroeconomy and the energy supply sector: Taxes and subsidies

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December 1996

Paper submitted to 20th IAEE International Conference, January 22-24 1997, New Delhi, India

ABSTRACT

This paper analyses taxes and subsidies as an instrument to ensure a reduction of emissions from electricity and heat production. A model of the energy supply sector of Denmark developed at Risø National Laboratory is used to analyse the possibilities of reducing CO_2 emissions from electricity and heat production through fuel tax and subsidy incentives. The energy supply model is linked to a macroeconomic model such that macroeconomic consequences of tax policies can be analysed along with consequences for specific sectors as agriculture.

All major electricity production units in the Danish system are included in the model with a technical description of production parameters including fuel substitution possibilities. Electricity and heat are produced at heating and power plants and utilising fuels which minimise total fuel cost, while capacity expansion technologies are regulated by the authorities. Direct regulation and regulation through economic incentives are dependent on each other. The effect of restricting the expansion of production capacity to a specific fuel technology is very dependent on the extent to which electricity producers are free to choose between fuels and the different production plants. Introduction of new plants characterised by a fuel mix with heavy fuel costs could lead to use of the plant only for supplying peak demand thereby leading to a much smaller reduction in emissions than anticipated. Contrary to this the effect of fuel taxes and subsidies on fuels is very sensitive to the fuel substitution possibilities of the plants in the production system and consequently the extent to which expansion technologies have been regulated. Taxes are imposed relative to the CO_2 content of fuels, and tax revenues are redistributed towards use of fuels with low CO_2 content.

It is shown how relatively small taxes and subsidies can produce significant shifts in the fuel input mix, when the expansion of production capacity is regulated to ensure a flexible fuel mix. Policies to ensure a more intensive use of such relatively expensive renewable energy sources as biomass could be implemented with only small taxes and subsidies. Subsidies could encourage the use of renewable energy sources as biomass for electricity production and contribute to a sustainable development in the use of fuels. Subsidies for biomass use could eventually lead to an increasing and more efficient production of biomass.

INTRODUCTION

The energy supply sector is very important in any analysis of emissions and options for reducing emissions. In the Danish case the CO_2 emission from this sector today accounts for more than 50% of total emissions. Traditional top-down analyses of tax-incentives to reduce emissions have not been directed at analysing special conditions in the energy supply sector. Long-term analyses have been carried out with emphasis on the energy supply sector and the investment decision between technologies based on different fuels. Medium-term capacity constraints and related constraints on technology as fuel substitution possibilities in this sector are important factors with respect to analysing CO_2 tax policies. Price elasticities are far from constant and could be even infinite as substitution possibilities for switching fuels at short notice could be large on existing production capacity. In the Danish case a considerable share of electric power plants can switch fuel between fuel oil and coal from month to month or even on shorter notice. The policy adopted for technological implementation in new production capacity might increase the number of fuels among which the plants are able to substitute in the future. Multi-fuel plants have investments cost only slightly higher than the traditionally build coal fired plants in Denmark. The flexibility regarding future price developments or changing environmental constraints might heavily outweigh this extra cost.

Substitution possibilities in the Danish power sector are modelled in detail in a project carried out on integrating top-down and bottom-up modelling approaches. The energy supply sector and specially the power sector is modelled in detail including the links which exist to the macroeconomy and the links from the macroeconomically determined demand for electricity and heat. Unlike most bottom-up studies that do not include price induced feed-back effects on energy demand (Chandler, 1994) the model used here through the link to a macroeconomic model and an iterative procedure takes explicit account of this interaction with economy.

Taxes and subsidies on fuels used in the energy supply sector can be analysed in this model setup, but the model is not suitable for analysing fuel substitution and the subsidising of certain fuels in the rest of the economy.

Biomass is treated as an important fuel alternative and is seen as one of the policy options with respect to the technologies that are relevant to include when expanding or replacing power production capacity. The link with the economy is included both with respect to the biomass demand and the effect on the total macroeconomy, but there is no description of the supply side of biomass in the model used here.

MODEL DESCRIPTION

The model of the energy supply sector is a bottom-up based simulation model with many technological parameters. The model also features important top-down elements, e.g. running production cost of electricity and heat at the large plants are minimised given fuel prices. The minimisation is carried out with respect to the demand given from the macroeconomic setup and capacity and technology given by existing capacity and policy-determined capacity expansion characteristics.

Links between the energy supply sector and the macroeconomy have been established and the energy system is this way an integrated part of the macroeconomy. The macroeconomic setup used is ADAM (Annual Danish Aggregated Model), which is an econometric based keynesian type of model and the most common used macroeconometric model in Denmark. It is only the energy supply sector in ADAM that has been replaced by the bottom-up module of energy supply described in detail below.

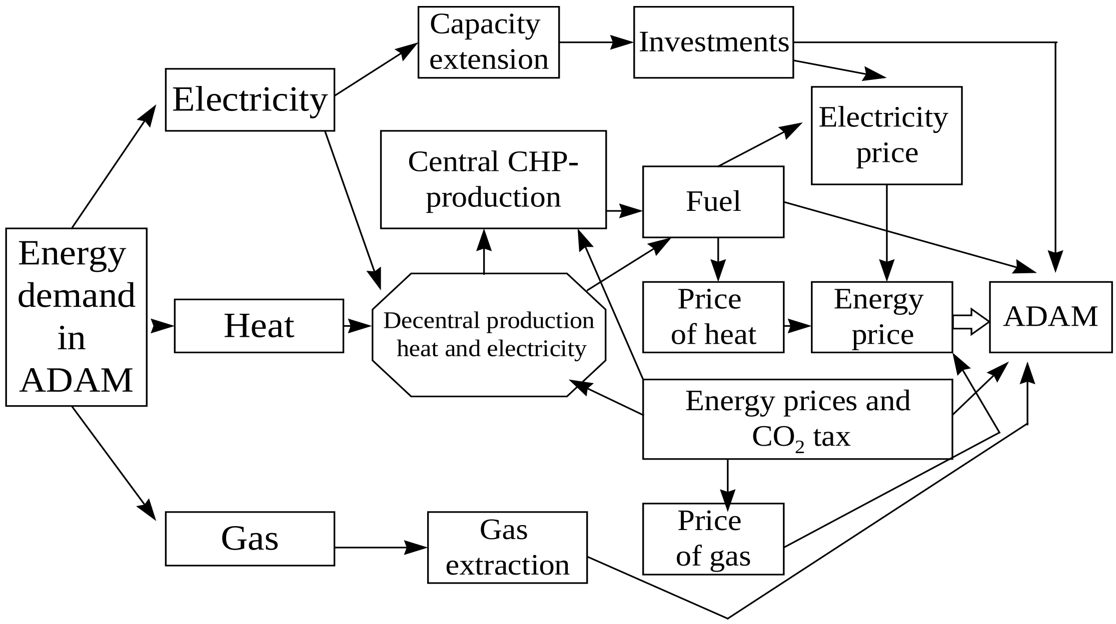

Figure 1. The energy supply sector and its links with the macroeconomy

The Danish power sector has traditionally been regulated by the authorities and this is reflected in the model in different planning and regulatory elements. The expansion of electricity production capacity based on renewable energy sources is directed by policy and the expansion of this production category is regarded as exogenous in the model. Wind power, decentral combined heat and power plants and industrial cogeneration are all handled in this way. Only the expansion of capacity by the major utilities is related to electricity demand.

Production capacity is expanded according to a target of 20% reserve production capacity at peak levels of domestic electricity demand. It is the capacities of the large central power plants that have to be adjusted to reach the target. The model includes the possibility of handling the import and export of electricity given the transmission capacity and fixed import and export prices, which are not necessarily at the same level.

Much of the Danish energy supply system is based on combined heat and power production and the model includes a detailed description of the coproduction problem. The model includes a load curve for electricity demand but heat demand is taken as total yearly demand; no account is taken, however, of the geographical restrictions on heat demand that are quite relevant in the Danish case.

The secondary capacity of wind power, decentral combined heat and power and industrial cogeneration are all producing at their capacity but with an exogenous number of yearly production hours. The primary production capacity faces a residual electricity and heat demand. Production is allocated to individual plants in the primary system from a minimisation of production cost of the given heat and electricity demand and from a duration curve of electricity demand. All primary production plants are described with their technical characteristics as: fuel mix and substitution boundaries, fuel efficiency, heat capacity, factor of electricity loss to heat produced and the remaining physical life time.

A detailed description of the Danish electricity and heat production system is important for analysing the medium- term options in the system. With a horizon of up to 15 years any kind of analysis of CO_2 emissions, taxes and subsidies will be very dependent on the existing production technology of electricity and heat production. This is certainly the case in Denmark, where the system is characterised by slow growth of demand and some excess production capacity at present. Further, the expansion of secondary production capacity postpones the introduction of new technology with increased flexibility and fuel substitution in the primary electricity and heat production sector.

Price determination is an important element of the link between the energy supply sector and the macroeconomy. The price of electricity is determined from the cost of producing and distributing electricity. Fuel cost, other material inputs, labour cost, appropriations and depreciation are included following the requirements of the Danish legislation.

Danish legislation precludes the existence of profits in the power sector. This mean that any profits of the total production and distribution system must be returned to consumers by adjusting the electricity prices the following year. This is included in the model as a no-profit rule. Other features of Danish legislation are the very favourably conditions for appropriations connected to investments. In the five-year construction period of large power plants 75% of total construction cost can be appropriated and thereby included in electricity prices. Investments in the production and transmission capacity of the power sector is hereby paid by consumers in advance. The model takes account of this relation as well.

The price of electricity responds to changes in fuel prices including taxes and subsidies. Through the link to the macroeconomic demand for electricity the response in demand is fed back to electricity production. Thus the effect of taxes on fuel consumption in the power sector includes two effects: substitution between fuels in the power sector and a reduction of electricity demand from the macroeconomic part of the model.

Properties of the energy supply model relevant for analyses of taxes and subsidies include:

- Infinite substitution between fuels at relative trigger prices for the individual plant.
- Segments of power sector without substitution.
- Policy-dependent development of future substitution possibilities through the distribution of new capacity on different technologies.
- Electricity demand development influencing electricity capacity expansion speed and thereby the introduction of technologies with substitution possibilities.
- Effects on biomass production, economic growth and foreign balances are found.
- The substitution options and technological characteristics of electricity and heat production are very dependent on the time pattern of the scrapping of existing production capacity.

The important links between energy supply sector and macroeconomy are: electricity and heat prices, investments, fuel demand and the feed-back from the macroeconomic determined electricity and heat demand. Changing economic conditions have important impacts on the energy supply sector. In the short run demand for electricity and heat determine production and in the long run demand determine power and heat capacities. Price of expanding production capacity is dependent on the price for investments determined in the macroeconomy. In the Danish power sector wages and other inputs apart from fuel accounts for about 75% of total costs and thus the output price from the energy supply sector is highly dependent on the general price level of the economy.

Effects from the energy supply sector on the economy are of less importance for the macroeconomy than the effect from economy to the supply sector. The main influence on the economy is seen from the output price of the energy supply sector. However, the direct impact of changes in fuel prices and taxes is more important for the economy than the effect which is seen through the energy supply sector as the fuel costs only account for 25% of total costs in the sector.

SUBSTITUTION

For all analyses of price incentives for reducing CO_2 emissions the substitution possibilities between fuels are vital. For the power sector substitution options can be relatively well described. An econometric analysis of substitution in the sector would hardly yield reliable results for substitution possibilities or fuel price elasticities. Many econometric specifications would include constant elasticities, which is certainly not the case in a sector where technological differences are relatively small between producers and the corresponding relative trigger prices of fuels do not differ much.

In a CGE model study of the Danish economy (Frandsen et. al., 1994) the energy supply sector is modelled with substitution between aggregates of energy, capital and labour but without substitution between fuels. Substitution is recognised to be relevant in the power sector between coal, natural gas and fuel, but this substitution possibility is not included in the model as this would require modelling of the relevant trigger prices. The bottom-up characterised energy supply model used here include a detailed description of technical parameters which in an endogenous way determine the trigger price for each individual production unit and the corresponding substitution between fuels.

In the model fuel substitution on each plant is described as taking place immediately as relative fuel prices changes in favour of another fuel. “Immediately” is used in the sense that we operate on a yearly basis.

Substitution in the model takes place through different channels, as listed below:

- Substitution between fuels in the individual plant.
- Substitution between plants with different fuel mixes and fuel costs.
- A policy determined substitution between fuel technologies in new and old production capacity.

The first possibility is the most important if the system already includes technology options for substitution between fuels. If substitution is limited in the existing system the policy option for regulating fuel technology is more vital.

In the existing capacity substitution takes place at the individual plant level, where the cost-minimising fuel mix is chosen within the technical boundaries for each specific plant. At the central combined heat and power plant level the production of each plant is determined by a marginal production cost and a load duration curve for the production that has to be delivered from the central part of the system. Substitution between plants with different fuel mixes takes place by decreasing the running hours of the plants with increased relative fuel cost and increasing the running hours for plants with decreased relative fuel cost. Policy-initiated fuel substitution (apart from taxes) is found in the way that substitution possibilities in the longer run are highly dependent on the fuel technology options of new plants and dependent on the mix between the expansion of renewable energy based production capacity as wind power and traditional production capacity.

Substitution possibilities are present in the existing Danish capacity mainly in the form of switching between coal and fuel oil and to some extent natural gas. The scenarios and their results referred to here assume that future production capacity expansion is dominated by multi-fuel combined heat and power plants. This implies the possibility of substituting as much as 50% biomass use in each new plant or almost 100% coal or fuel oil.

TAXES AND SUBSIDIES

Taxes as an incentive to reduce energy consumption or the composition of energy demand on different fuels have often been analysed in a top-down context. In here the application of taxes as a CO_2 tax is examined with respect to total society, but including a very detailed modelling of the energy supply sector with many bottom-up characteristics. The approach of this model implies that substitution between fuels are modelled in detail in the energy supply sector which is the sector that has the highest CO_2 emission and substitution possibilities in the Danish case.

Taxes and subsidies could be compared to direct regulation of fuel use for individual plants in the power sector or regulation of the use of specific fuels for all of the sector. Cost of regulation in efficiency terms will be higher for direct regulation than for taxation. This theoretical assumption is used as an argument for the use of taxes on fuels in the way that the individual plant is thought to minimise production cost and thereby switching to a fuel mix, which is not necessarily the same as the fuels mix they are forced to have by the regulation.

The argument of higher cost of regulation is more valid for a sector with many individually optimising units than for a sector which is centrally planned and optimised. This mean that the argument is less relevant in the present Danish case of optimising the total system, but the relevance might increase as deregulation is implemented and the production structure becomes more fragmented.

An important point when analysing economic costs of CO_2 taxes is the recycle principle for tax revenues used in the macroeconomic model. As the top-down part of the model is the most convenient part to recycle economy wide tax revenues the most obvious choice is recycling by lowering general tax rates. The effect of this recycling depends heavily on the properties of the macro model in question. If the model used or the economy examined includes many distortionary taxes or imperfections an optimisation of the recycle principle towards specific tax rates or towards cost of labour and capital could improve the overall effectiveness of the economy. Hereby the negative impacts on GDP of CO_2 taxes could be reduced or even eliminated.

Often effects from recycling revenues are referred to as a “double dividend” from green taxes. As mentioned in Cline, 1991 it is difficult to explain why the political system is incapable of rationalising the tax structure in the first place and thereby achieve a second dividend. This leads to the conclusion of analysing primarily long term production function effects of carbon taxes.

The different recycling principles are often seen as an integrated element of analysing emission reducing initiatives. Recycling effects on the economy that works through non-energy relations should not be seen as an effect of the emission initiative but instead as a consequence of the model used and the imperfections of the economy examined. Such recycling effects could in many cases be achieved by changing the tax structure, improving the labour market functioning or reducing other distortionary relations in the economy.

In a study on green taxes in the Danish case (Frederiksen, 1996) use an empirical general equilibrium model to evaluate a wide range of recycling principles. The model used in this study shows the divergent results on economy from different principles, but as it is a general tax on business energy use that is analysed it is only general options for recycling to business as a whole that is analysed. In this study results of increasing energy prices by 50% range from a negative impact on the present value of GDP of 3% to 70%.

The question of recycling is important in all top-down analysis of costs of reducing emissions but is generally not acknowledged in bottom-up studies. Linking the two modelling approaches leads to a recycling in the top-down or macroeconomic part of the model, but the revenues determined in the macroeconomic part of a linked model might just as well be recycled in a bottom-up module which determines fuel demand in the energy supply sector.

In here the recycle principle is analysed with respect to the difference between an economy wide cutting of corporate tax rates and recycling of tax revenues from the energy supply sector to the sectors own use of a specific CO_2 low or neutral fuel.

A tax imposed on all applications of energy is introduced and two alternatives of recycling of revenues are examined in the model setup described above.

a) A CO_2 tax of approximately 50 USD and a recycling of total revenue to industry through a lowering of the corporate income tax rate.

b) A CO_2 tax of approximately 15 USD and recycling of revenue from the electricity- and heat-generating sectors as subsidies to the use of biomass. Revenues from other sectors are recycled as in a).

The two alternatives are compared in Table 1.

By imposing taxes and subsidies as in b) fuel cost are following a path as in Figure 2. The immediate fall in the price of biomass to zero is caused by the lack of substitution possibilities towards biomass. Only as new capacity is build the substitution possibilities arises and the subsidy effect on the biomass price decreases as the use of biomass increases.

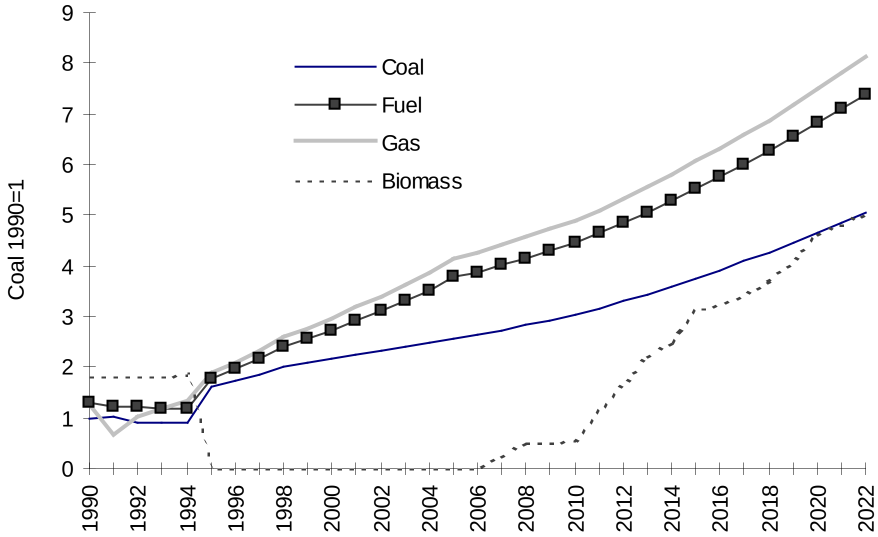

Figure 2. Fuel prices including taxes and subsidies

A CO_2 tax as in b) is not enough to initiate substitution from coal towards natural gas or fuel oil. If the tax revenues were used for subsidising use of natural gas there would initially be substitution towards natural gas. But the underlying price projections (originating from an IEA scenario) implies that in the long run taxes used for natural gas subsidising would not create substitution. All fuel used in the energy supply sector is subsidised both the price elastic and the inelastic part.

Prices used are nominal prices and including transport cost to the large power plants. Biomass is a domestic price projection based on present straw and wood chips prices and inflated with the same rate as agricultural products in the macroeconomy.

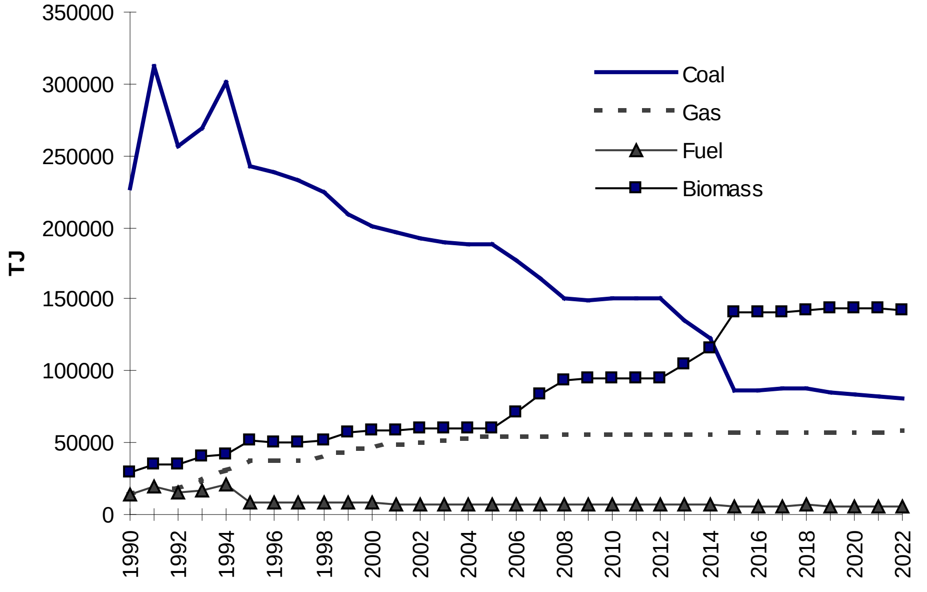

Figure 3. Fuels used for electricity and heat production with taxes and subsidies b)

Coal is originally the main fuel used in the energy supply sector, but the share of fuel decreases as biomass and to some extent natural gas increases. The first gradual increase in the use of these two fuels comes from the secondary combined heat and power units and from production of district heat. Fuel demand from these units are inelastic, but tax revenues are used for subsidising their fuel as well. As technical substitution possibilities from 2005 and on increases, when old power plants are replaced with multi-fuel plants, the biomass use increases to the new limits. As the biomass use around 2020 reaches a considerable share of total fuel the tax revenue is not enough to subsidise biomass use to the technical limits of biomass use. This is reflected in Figure 2 where the price of biomass converges to the price of coal.

Table 1. A comparison of CO_2 tax revenue recycling: (effect at 25 years horizon)

Recycling	CO_2 emission	Electricity price	GDP	Agricultural production
Recycling through corporate tax a)	-16.0%	20.9%	-1.36%	2.7%
Recycling through subsidies on biomass etc. b)	-15.0%	3.6%	-0.36%	2.8%

The substitution towards biomass in the energy supply sector is of the same amount in a) and b). The necessary CO_2 tax to trigger this substitution is considerably smaller in b) than in a), which leads to a GDP loss of about one-third of the loss in a).

The price of electricity will rise in both cases as total fuel costs increase as a result of the increasing use of the basically more expensive biomass. A falling electricity demand leads to higher unit production cost of electricity and gives another boost to prices.

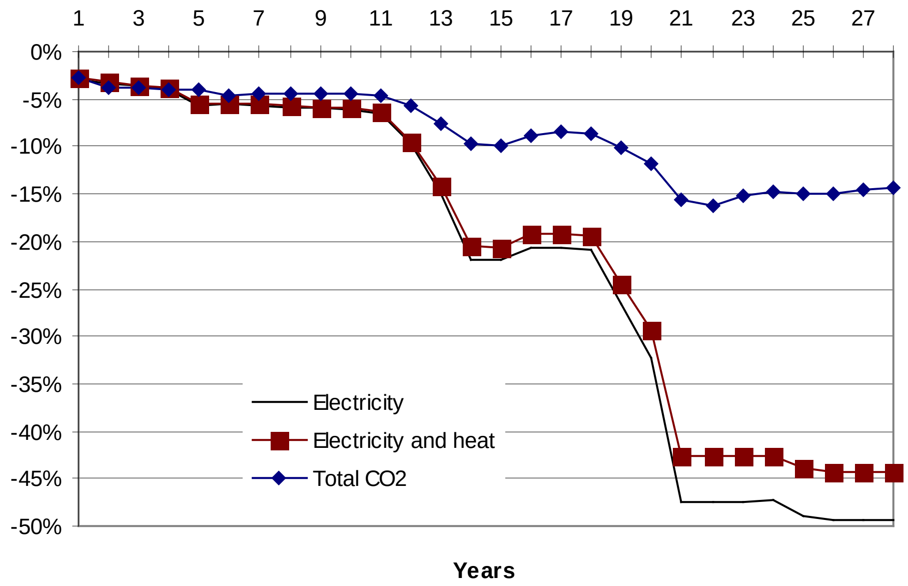

Figure 4. Emission reduction in alternative b)

The substitution in electricity production is limited by technical constraints on production capacity, and in both our cases the substitution is bounded by these limits. In our model substitution between fuels is much higher in the power sector, than in other sectors, which means that price incentives are more effective in reducing emissions here.

The reduction of emission in electricity and heat production accounts for about 85% of total CO_2 emission reduction in both case a) and b). In case b) the fall in demand for electricity and heat account for 10% point out of the 85% and thus 75% of the reduction can be attributed to substitution in the energy supply sector. Case b) includes a reduction in demand for electricity and heat of 10%, and thus the corresponding demand-driven reduction in the sector emission is 19% point out of 85% reduction. In case a) the substitution effect alone accounts for 66% of the reduction in emissions.

The economic costs of the two alternatives differ mainly as a result of the different tax levels necessary to achieve the same CO_2 emission reduction. A conclusion of this experiment with subsidies is that revenues from a CO_2 tax recycledd as subsidies towards CO_2 low or neutral fuels in the energy supply sector have much greater reduction effect than other ways of recycling, such as corporate taxes.

It is important to notice that the reduction effect in the energy supply sector is different from the reduction in the rest of the economy. In this model setup the reduction in energy conversion is a one time gain if the trigger prices for the substitution towards the least CO_2 -intensive fuel is reached, where reductions in the rest of the economy could be increased almost in proportion to increasing energy prices.

The increased biomass demand in both of the above cases is assumed to be supplied from domestic resources. In the model used here the agricultural sector is the only supplier, and production in agriculture increases, but this sector includes both agriculture and forestry. Obviously, the production of biomass could to some extent substitute other agricultural products but the magnitude of this effect depends on how productive the land that is now used for biomass production once was for producing other agricultural products.

In linking from biomass demand to agricultural production biomass is seen as a by-product from agriculture as straw or as produced on unproductive or unused land. The underlying production cost of biomass will be dependent on the demand level from the energy supply sector, but in here it is assumed that the demand is kept within the limits of by-products from agriculture and forestry and thus a relatively constant price is assumed within the biomass demand range analysed here.

CONCLUDING REMARKS

Analyses of CO_2 taxes as an instrument to reduce emissions have to take explicit account of the energy supply sector. A model as the one used in here could show the high reduction potentials from substitution between fuels in this sector, which can be achieved with only modest tax and minor implications for the macroeconomy. As the sector is characterised by high fuel substitution potentials the effect of recirculating tax revenues within the sector towards the use of fuels that have low or neutral CO_2 content, e.g. the use of biomass as in our case, is quite high. Use of subsidies towards biomass have positive consequences for agricultural production in the model used here mainly as a consequence of assumptions on the kind of biomass in question.

Compared to recycling of revenues in a standard fashion, where total CO_2 tax revenues are recycledd through the lowering of corporate taxes the method of subsidies in the energy supply sector implies a reduced impact on the economy as price effects on the international competitive position are much lower.

The conclusion regarding recycling and subsidies is dependent on the composition of the energy supply sector and fuel technology in the sector. In the Danish case the substitution possibilities are high today and will probably increase if new capacity will be mainly multi-fuel based. The Danish fuel mix of today with electricity production more than 90% based on coal, leaves very high technical potentials for substitution towards less CO_2 -intensive fuels, but this is not the general case of power systems throughout the world. CO_2 reduction from taxes and subsidies as in here will probably be of less importance in most other countries.

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